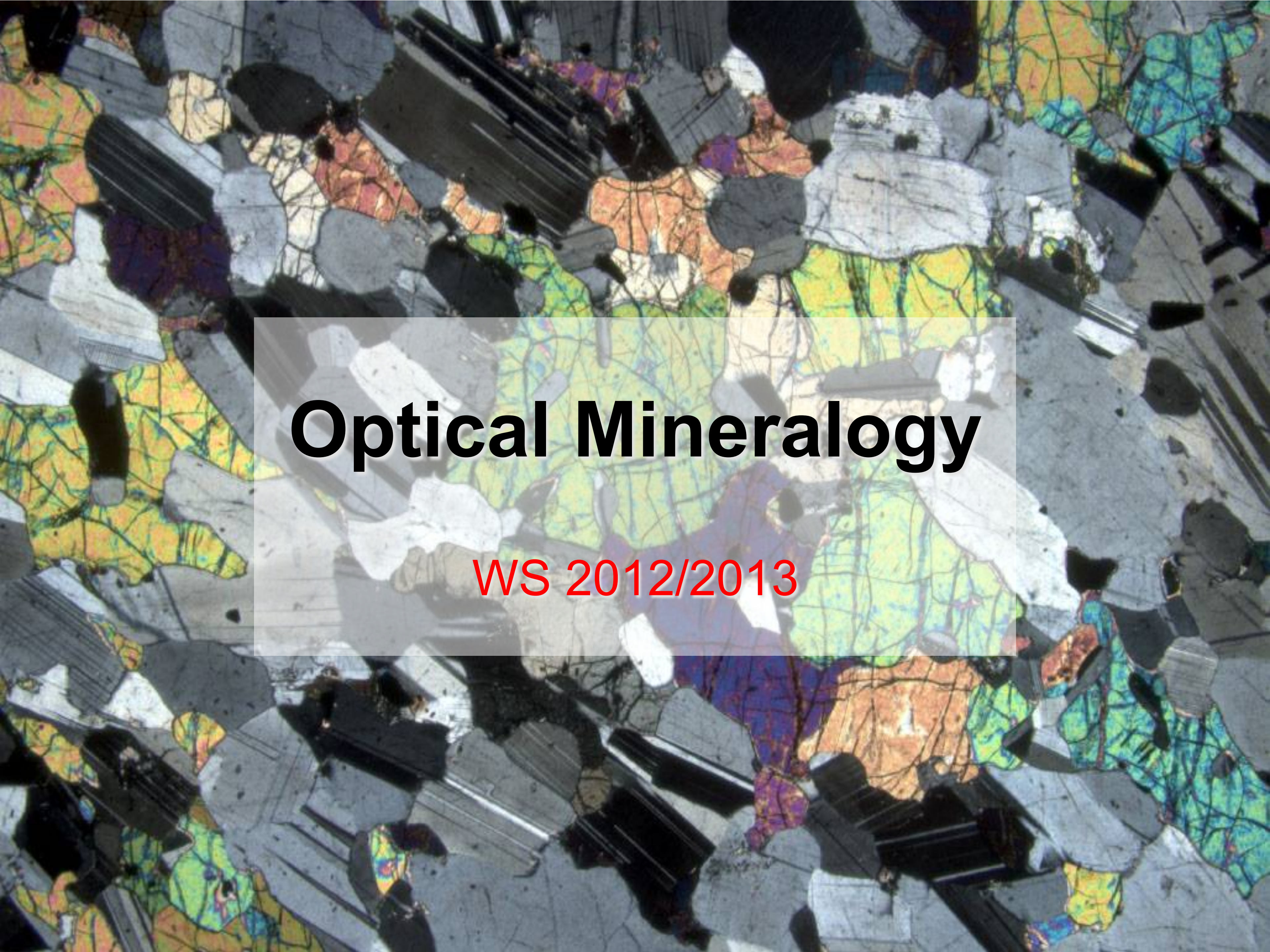


Optical Mineralogy

WS 2012/2013

Course structure

- THEORY OF OPTICS – first 6 or 7 weeks of lectures and practicals
- MINERAL CHEMISTRY – lectures January onwards
- IDENTIFICATION OF ROCK FORMING MINERALS – pracs January onwards
- EXAM – Week beginning February 4th

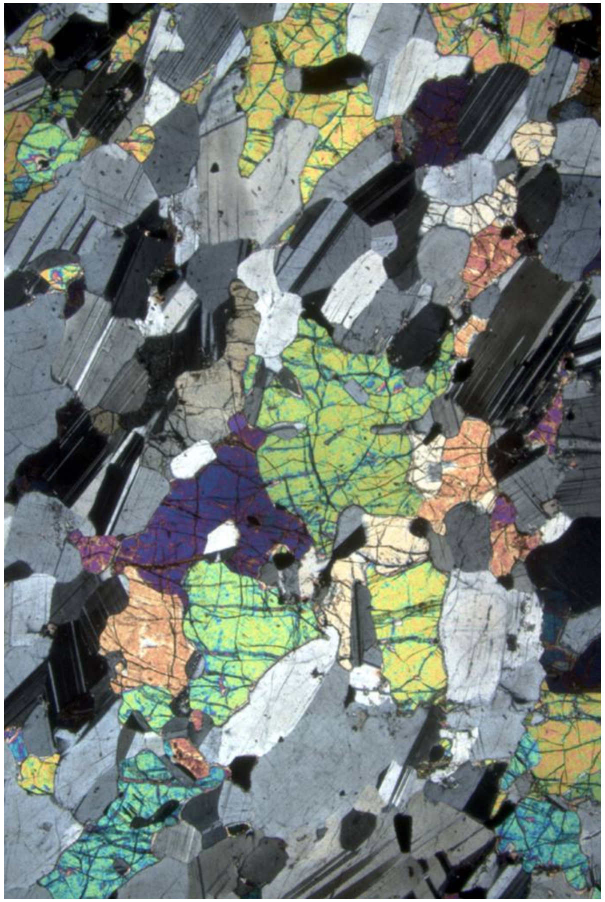
Website….

www.staff.uni-mainz.de/tjohnson/Internal/optics.html

- Downloads (pdfs) for lectures and practicals
- Mineral identification sheets
- Links to other resources
- Lots more....

There is lots of EXCELLENT freely available material (English and German) on the internet….

Why use a polarizing microscope??



- **Mineral identification**
- Rock identification
- Microstructural/textural investigation

….this leads to (for example)….

- Crystallisation sequence (igneous petrology)
- Deformation history (structural geology)
- Infer reactions & *P*–*T* (metamorphism)
- Diagenetic processes (sedimentary petrology)
- Alteration processes (e.g., weathering)
- .... and it is CHEAP ....

Minerals you will learn – 20(ish)

Garnet
Olivine
Clinopyroxene
Orthopyroxene
Hornblende
Glaucophane
Biotite
Muscovite
Chlorite
Epidote

Spinel
Cordierite
Andalusite
Sillimanite
Kyanite
Staurolite
Calcite
Plagioclase feldpar
Alkali feldspar
Quartz

What is the nature of light?

- Particles or quanta – photons (Newton) ?

…or…

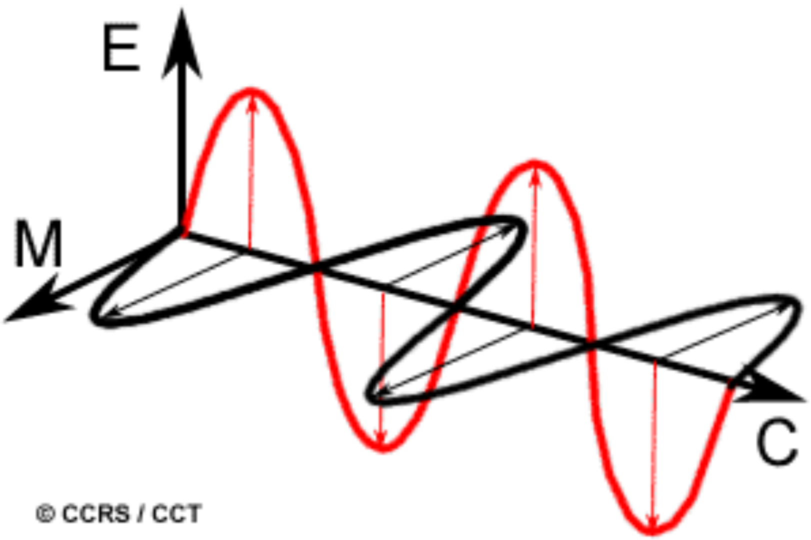
- Electromagnetic Waves (Huygens) ?

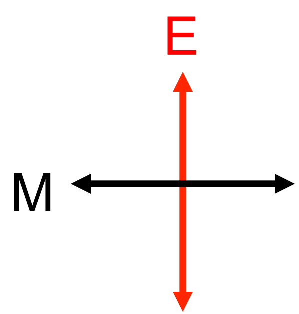
….it's both….

Particle-Wave duality (e.g. Einstein, de Broglie)

For the purpose of mineral optics, light is best explained as a WAVE….

Electromagnetic Radiation





Transverse waves that are mutually perpendicular

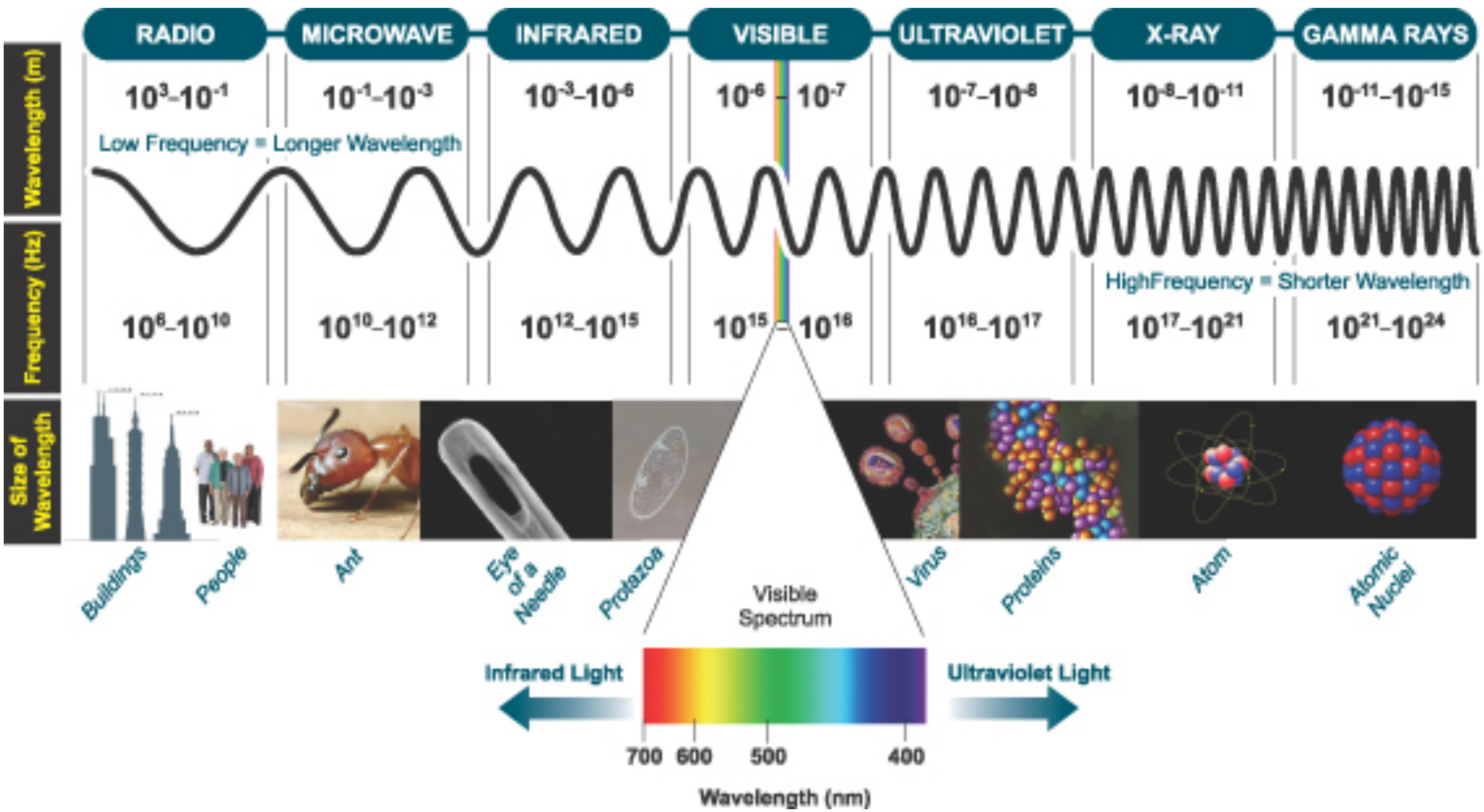
E = Electrical field

M = Magnetic field

C = Propagation direction

For crystal optics we only need to consider the electrical field

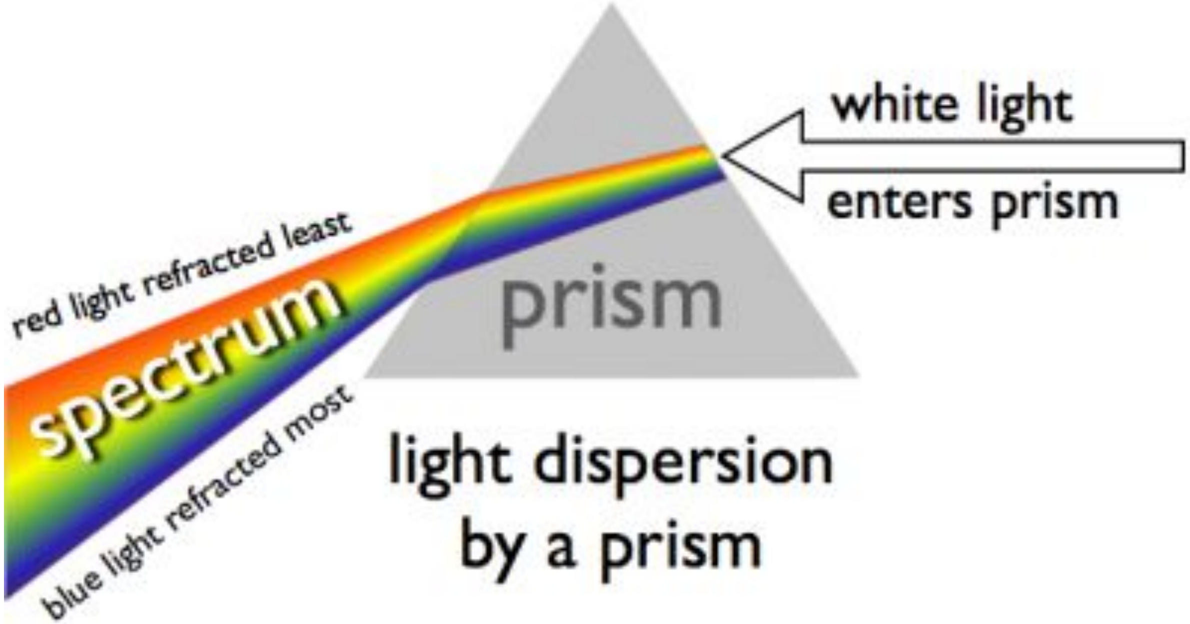
The Electromagnetic Spectrum



The Visible Spectrum

DISPERSION through a prism shows us that white light consists of a mixture of all colours of the visible spectrum....

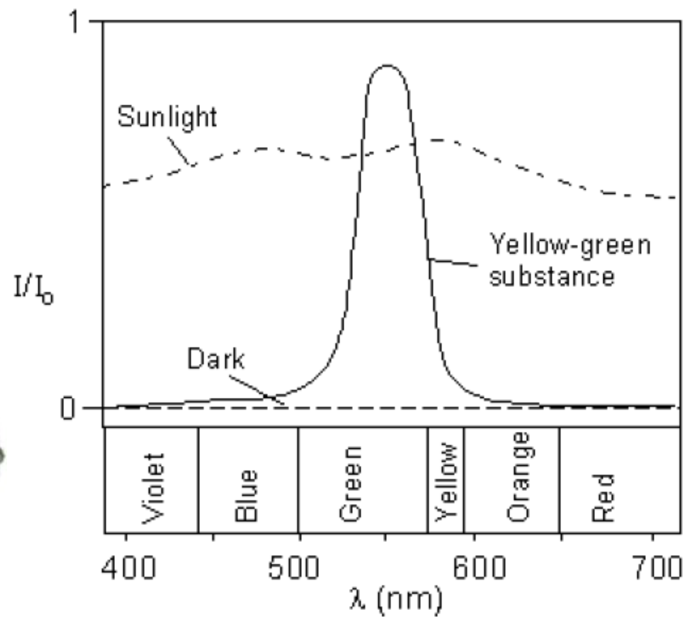
Visible light: 750 nm (red) → 400 nm (violet)



Colour

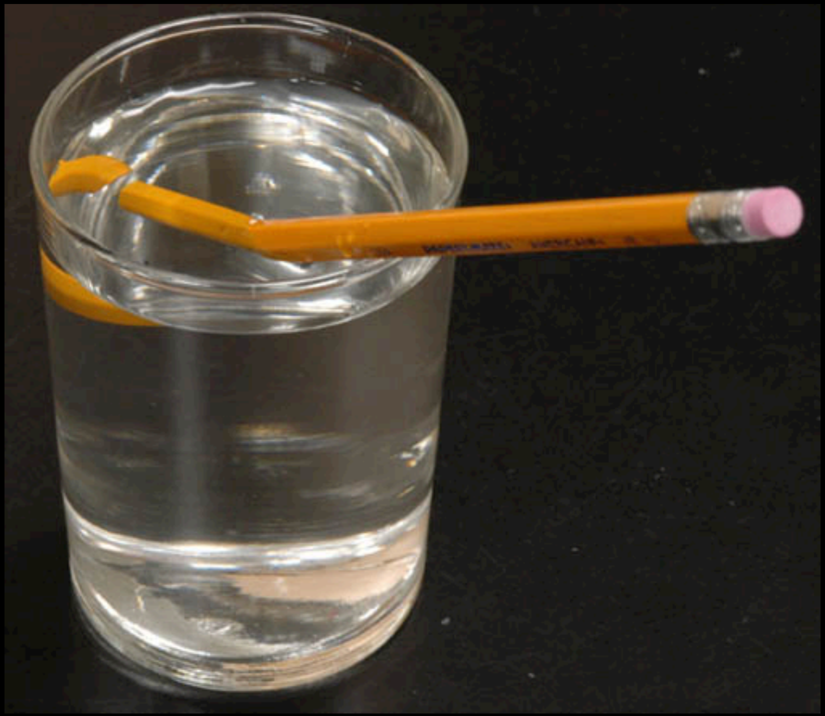
Absorption and Colour

- Selective absorption of certain wavelengths → Absorption colour
- The absorption colour is complimentary to the absorbed wavelengths!
- An example: a green mineral (e.g. hornblende):
  - Red/orange and blue/violet wavelengths are absorbed
  - Transparent for green light

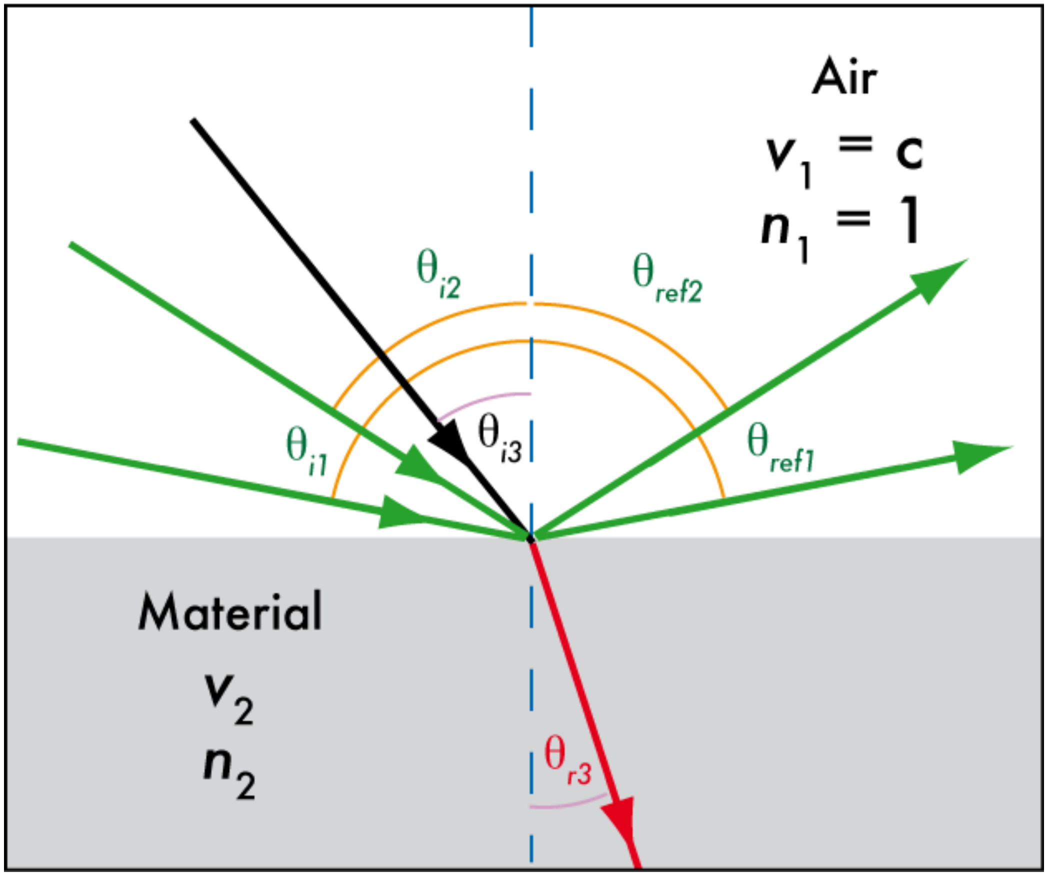


Note: Very rarely, colour effects are from interference and diffraction

Reflection and Refraction



Reflection and Refraction



1) Reflection:

Angle of Incidence = Angle of Reflection

$$(\theta_{i1} = \theta_{ref1;}\ \theta_{i2} = \theta_{ref2})$$

2) Refraction:

Angle of Incidence ≠ Angle of Refraction (light is ‘bent’)

$$(\theta_{i3} \neq \theta_{r3})$$

Velocity of light and refractive index

The ratio of the velocity of light in a vacuum/air (c) to the velocity of light through a material (v) is called the Index of Refraction or Refractive Index (n):

$$\boxed{n_m = c/v}$$

n is inversely proportional to v

$(n_{air} = c/c = 1)$

Light is slowed down when it enters a denser material, so $n_m > 1$. This slowing down reduces the wavelength of light (the energy and frequency stay constant):

Velocity of light: $v = f\lambda$ Light energy: $E = hf = hv/\lambda$

h = Planck's constant; f = frequency (remains constant); λ = wavelength;
$c \approx 300\,000$ km/s; v = velocity of light in a material ($v < c \rightarrow n > 1$)

Refraction – Snell's Law

$\sin\theta_i = AB/CB \rightarrow CB = AB/\sin\theta_i$
$\sin\theta_r = CD/CB \rightarrow CB = CD/\sin\theta_r$

$\rightarrow AB/\sin\theta_i = CD/\sin\theta_r$

…but… $v_1 = AB$ and $v_2 = CD$

$\rightarrow v_1/\sin\theta_i = v_2/\sin\theta_r \rightarrow$

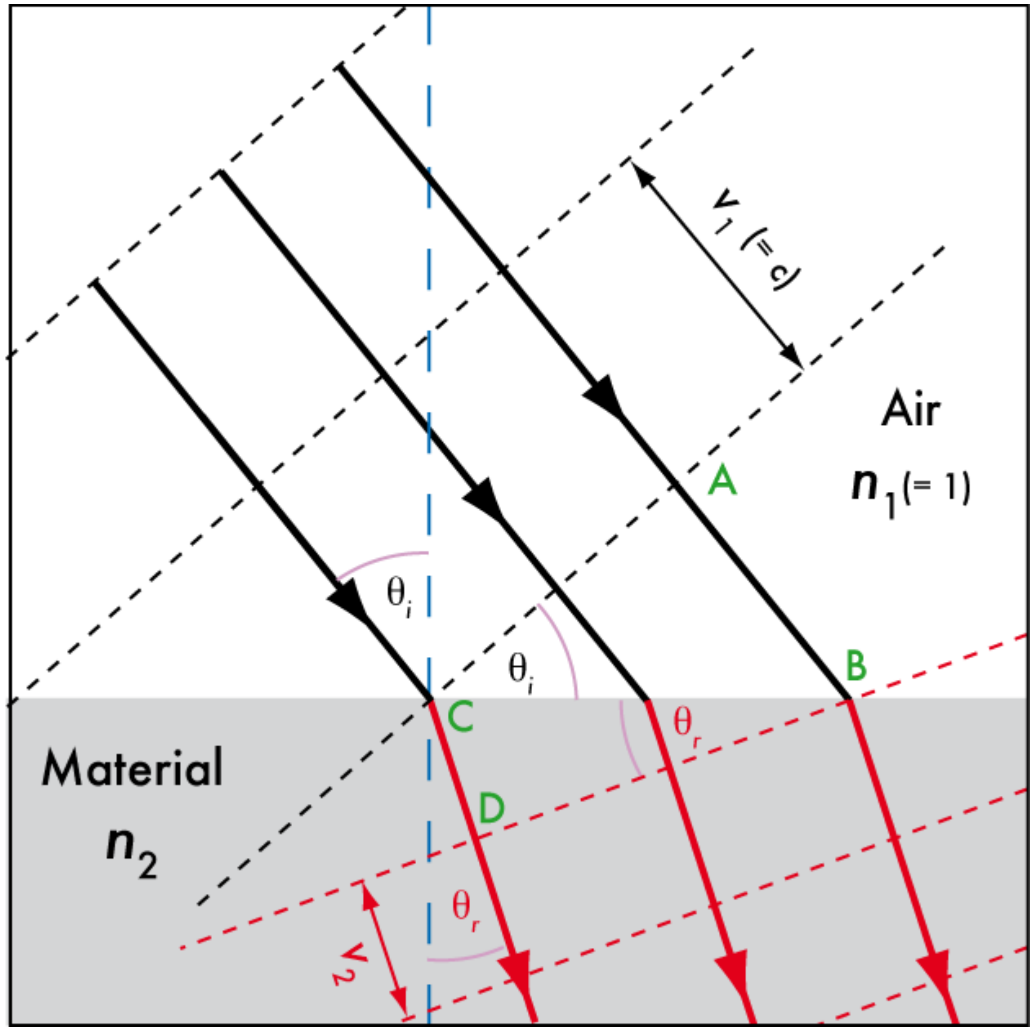
Snell's Law

$v_1/v_2 = \sin\theta_i/\sin\theta_r = n_2/n_1$

....as $n_2=c/v_2$, and $n_1=1$....

$$\boxed{n_2 = v_1/v_2 = \sin\theta_i/\sin\theta_r}$$

Note: v_2 is difficult to measure but $\sin\theta_1$ and $\sin\theta_2$ are not ….

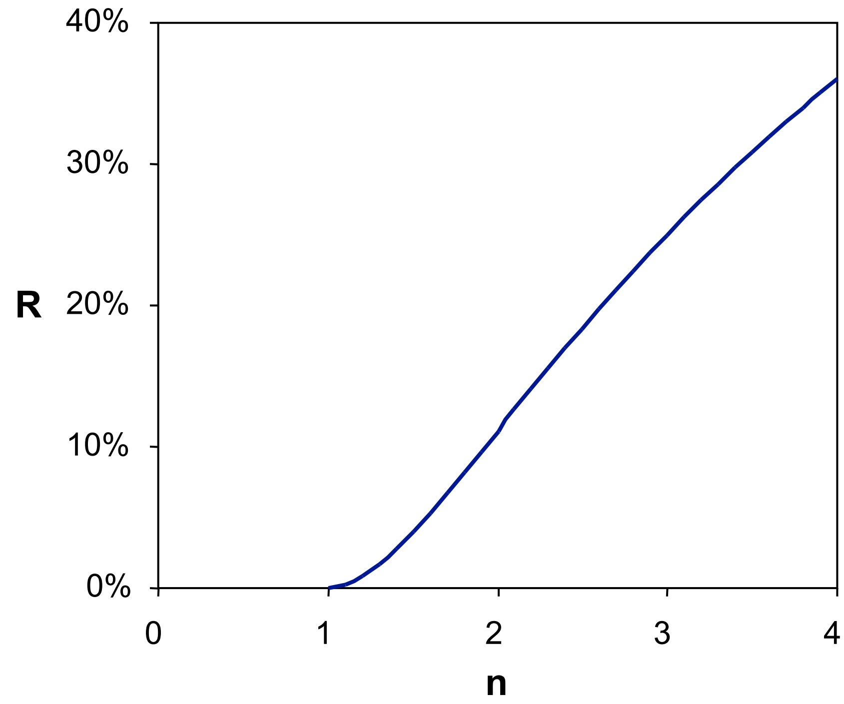


Reflectance

Reflectance, *R*:

$$R = \frac{I_R}{I_0} = \frac{(n-1)^2}{(n+1)^2}$$

I_0 = Intensity of incident (source) light
I_R = Proportion of reflected light
n = Refractive Index



Lustre

Glassy:	n = 1,3-1,9 → R = 1,7-10%
Adamantine:	n = 1,9-2,6 → R = 10-20%
Sub-metallic:	n = 2,6-3 → R = 20-25%
Metallic :	n > 3 → R > 25%

Total Internal Reflection and the Critical Angle

Snell's Law: $n_2 \, . \, \sin\theta_{int} = n_1 \, . \, \sin\theta_{ext}$

$n_2 \sin\theta_{crit} = n_1 \sin(90°)$

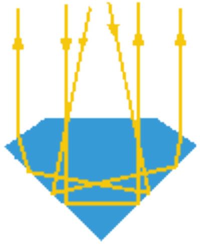
$\sin(90°) = 1, \; n_1 = 1$

$n_2 \sin\theta_{crit} = 1$

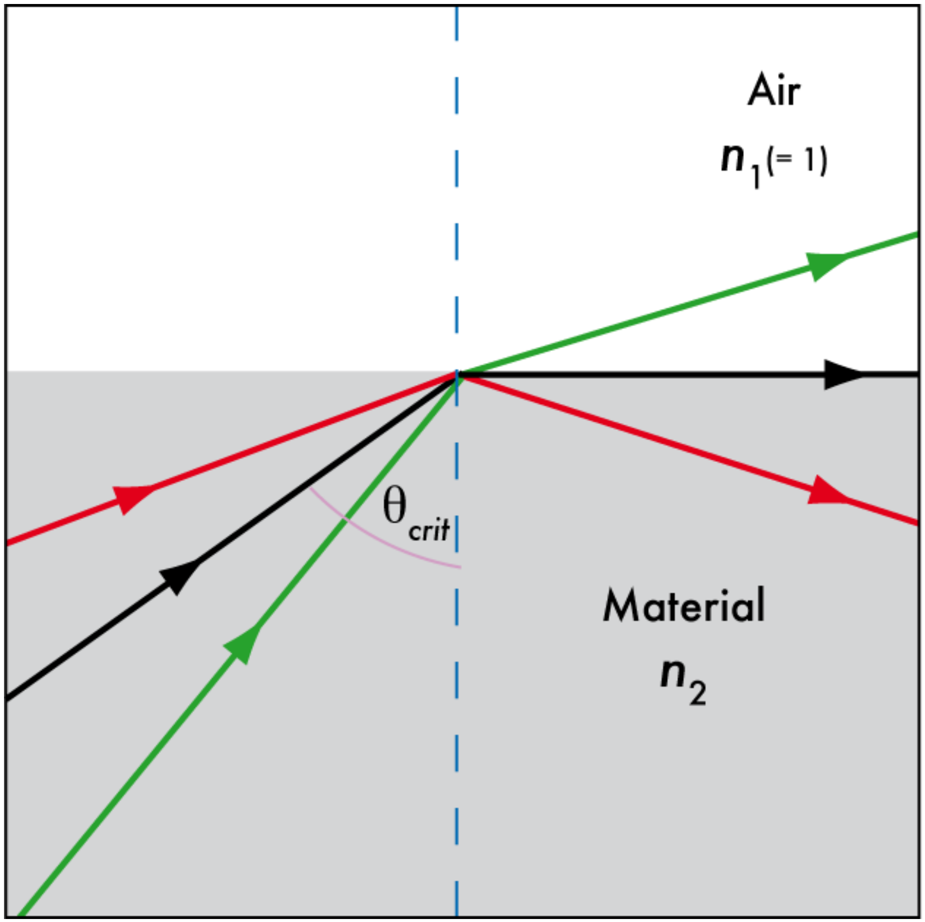
$\sin\theta_{crit} = 1/n_2$

If $\theta > \theta_{crit}$ = T.I.R.

Example: Diamond



$n = 2{,}42 \rightarrow \theta_{crit} = 24°$



Dispersion

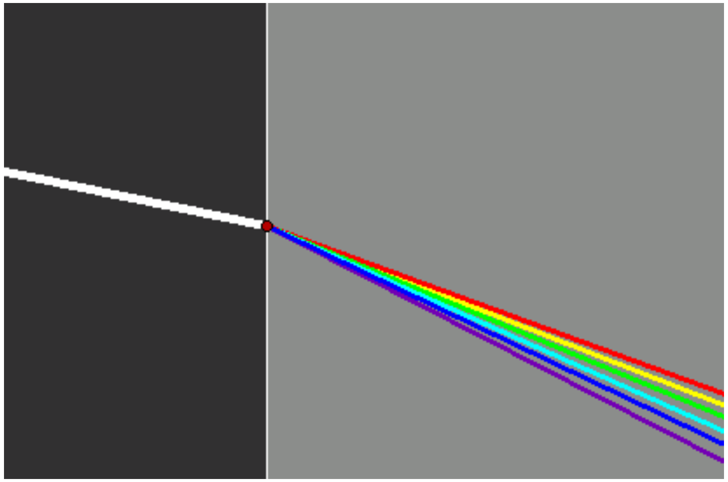
Dispersion

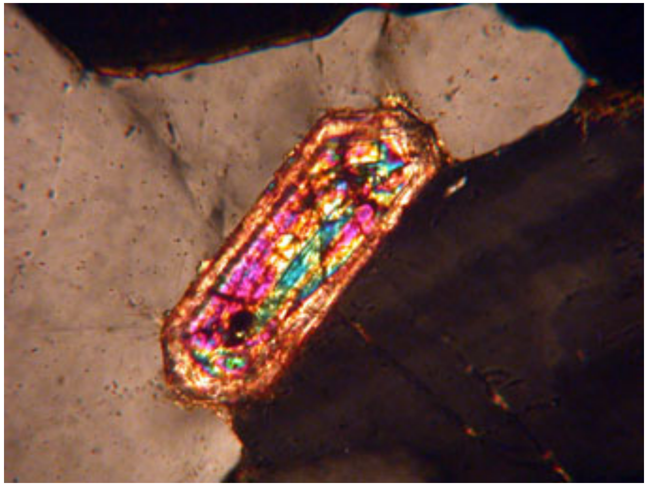
The refractive index of a material depends on the frequency and/or the wavelength of the light. - i.e. red light, with a longer wavelength, is refracted less than blue light:

$$n = c/v \rightarrow n = c/f\lambda$$

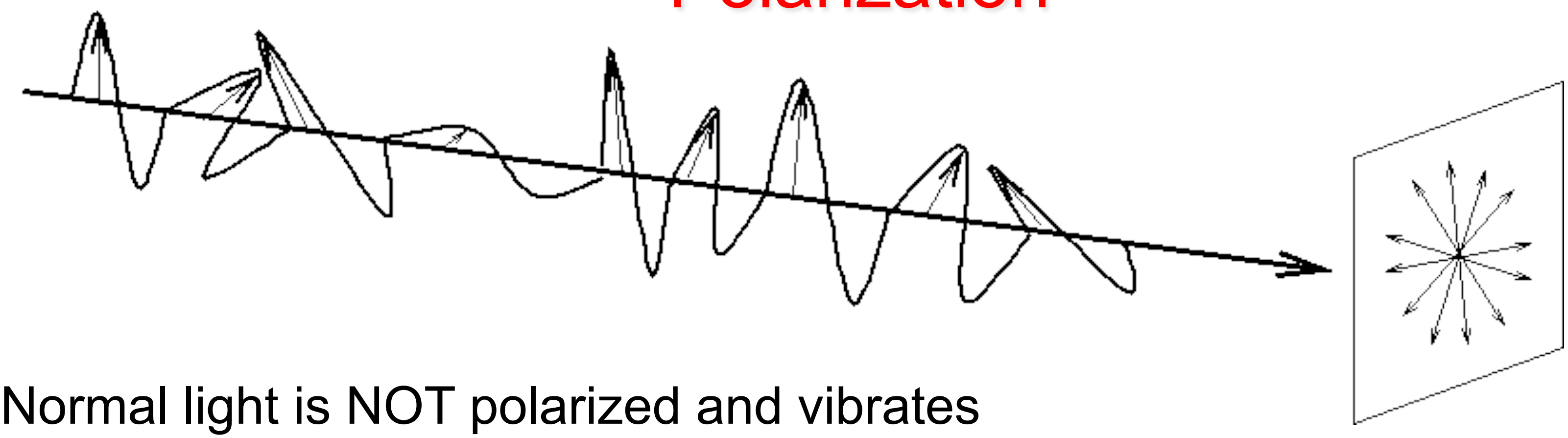
For most minerals, dispersion is small and not a problem.

However, with other minerals it can be a problem as it affects the other optical properties (e.g. sphene, zircon, some amphiboles)….



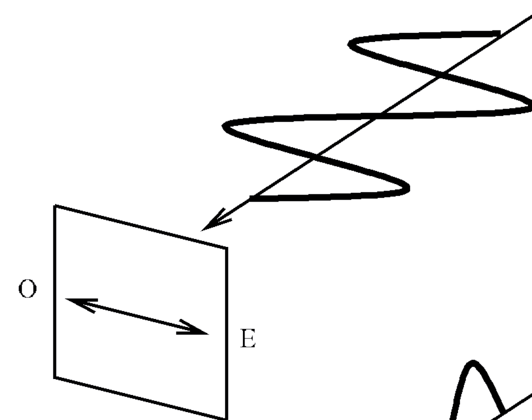


Polarization

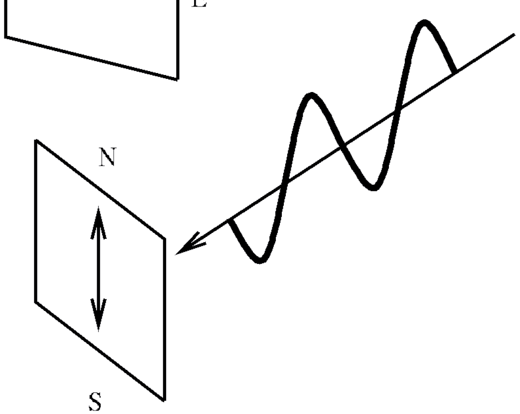


Normal light is NOT polarized and vibrates in all possible directions!

Plane polarized light (PPL) → only vibrates in a single plane. Light can be polarized by:



- Reflection
- Double refraction
- Selective absorption
- Dispersion

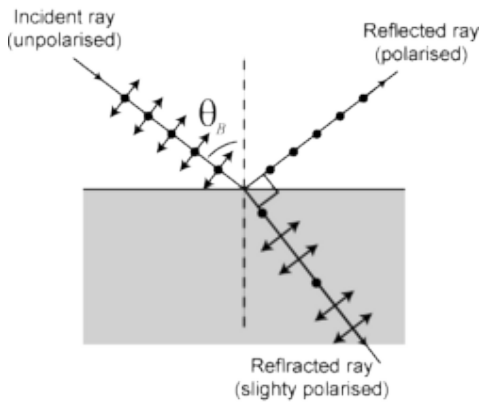


Polarization by reflection

- Reflected polarized light is parallel to the surface
- Maximum polarization occurs when the angle between the directions of the reflected and refracted beams is 90°:

BREWSTER'S ANGLE θ_B

$$\tan\theta_B = n$$

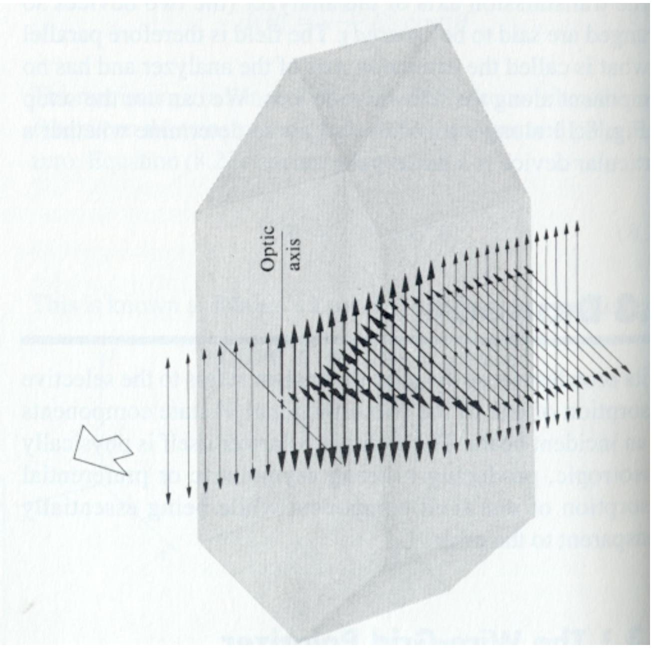


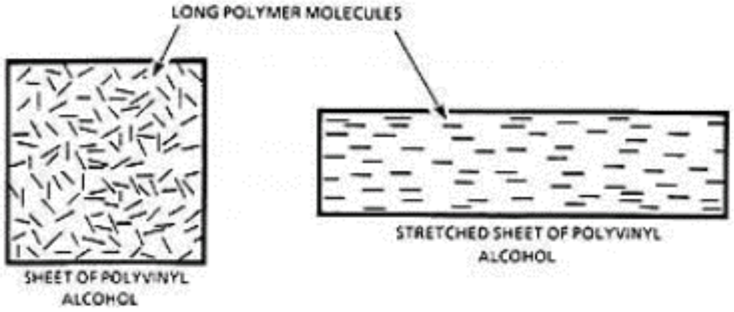
Polarization by selective absorption

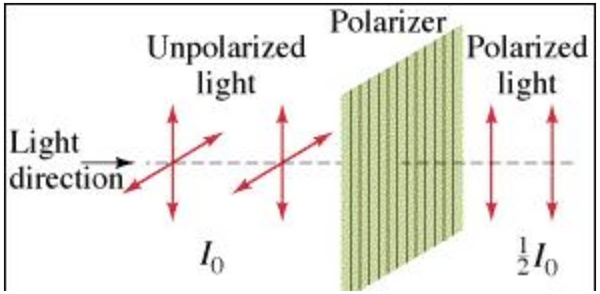
Dichroism = preferred absorption of particular oscillation directions:

Tourmaline - a naturally occurring mineral

Polaroid - a type of synthetic plastic sheet used to polarize light

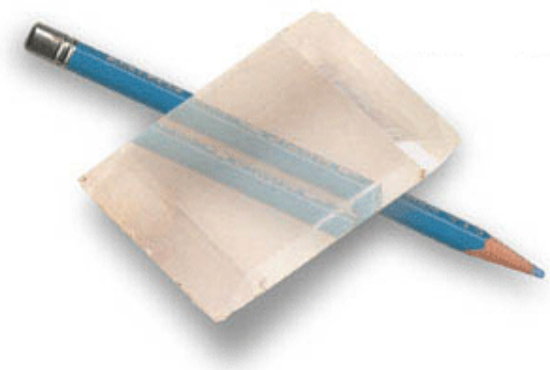


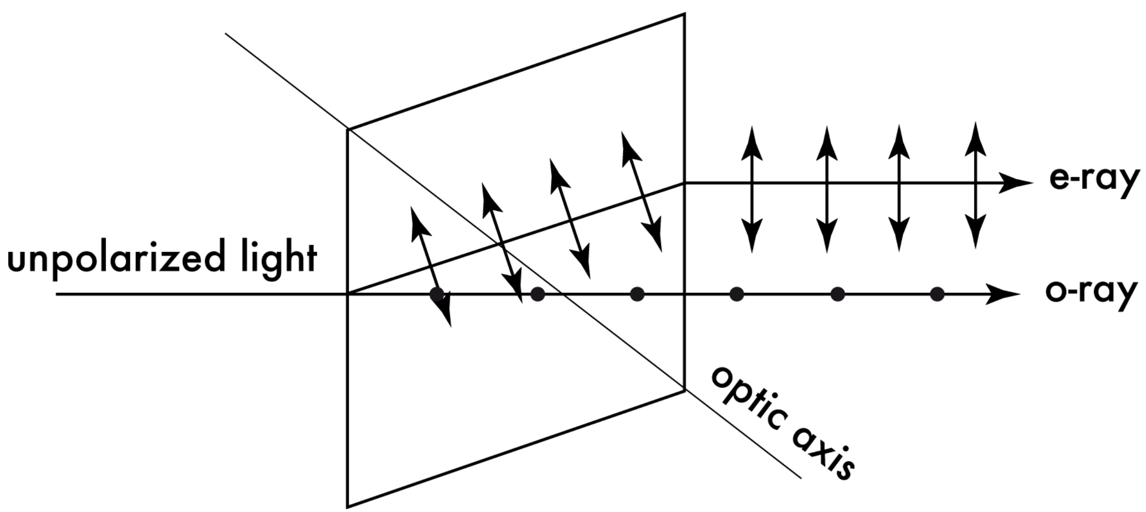




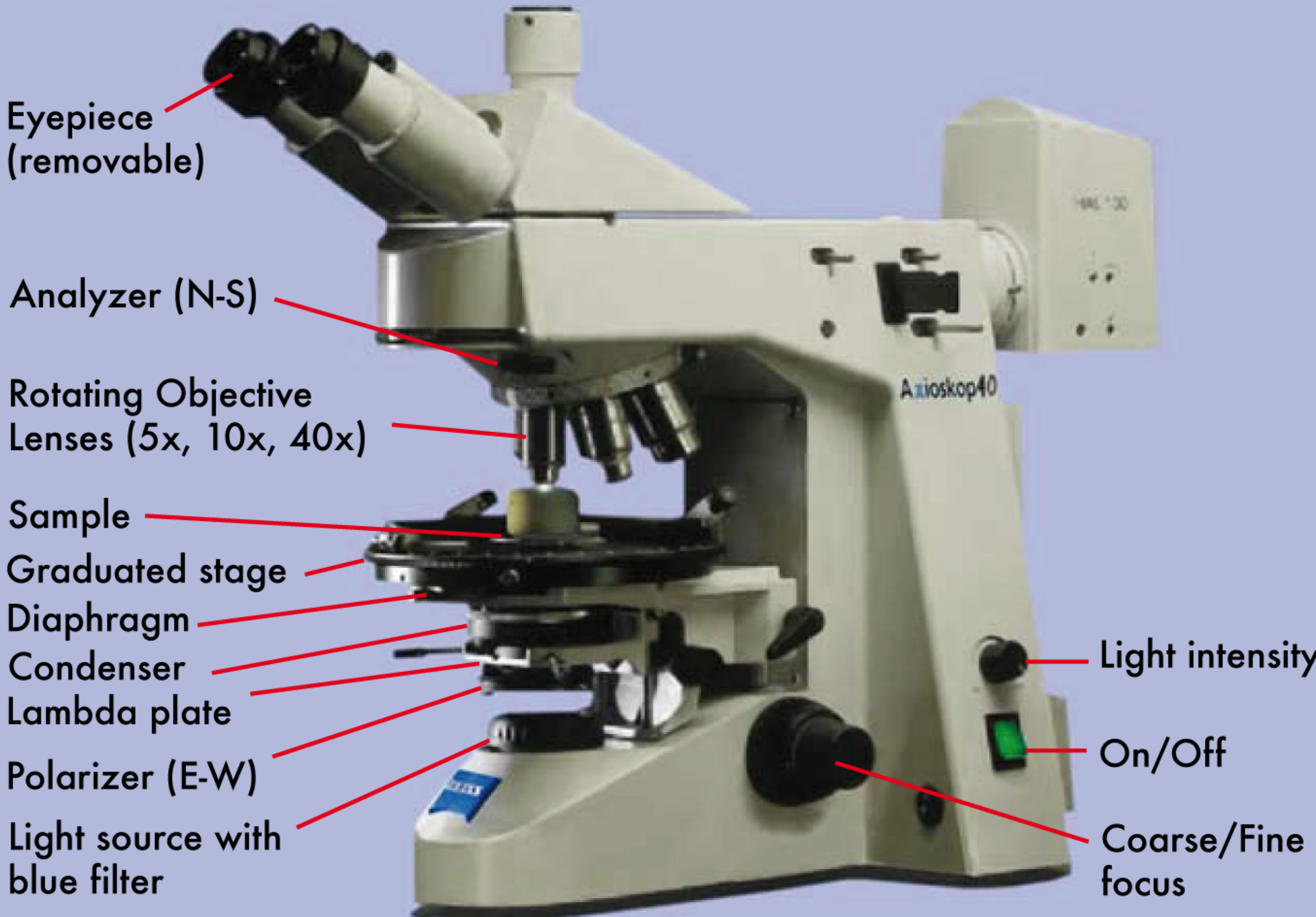
Polarization by double refraction

- In most minerals (all except those of the cubic system), non-polarized light is split into 2 polarized rays
- The rays have different *n* → Δ*n* = BIREFRINGENCE
- These rays are mutually perpendicular
- Example: calcite rhomb - light is split into an ordinary ray (o-ray) and an extraordinary ray (e-ray)





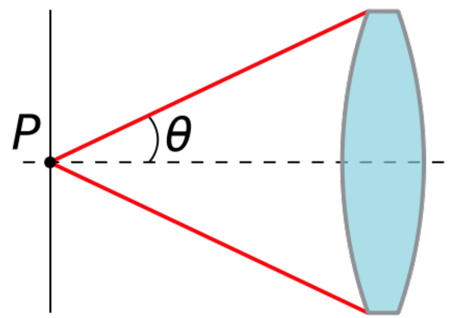
The Polarizing Microscope



Objective and Ocular lenses

- Magnification = Objective × Ocular:
  - e.g. 40 × 10 = 400x

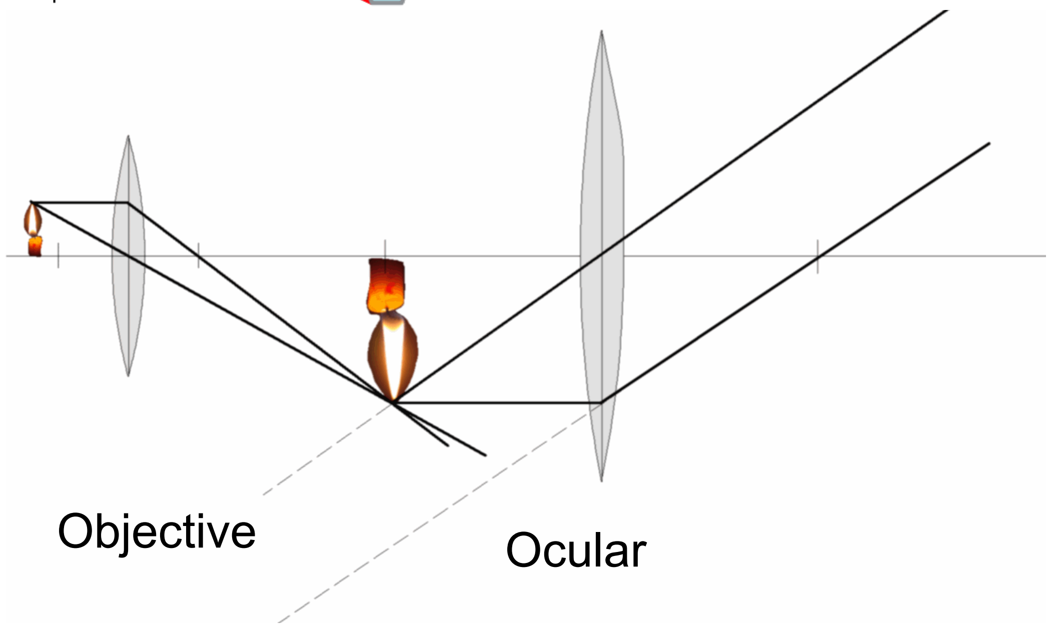
- Numerical aperture, A:



$$A = n \cdot \sin\theta$$

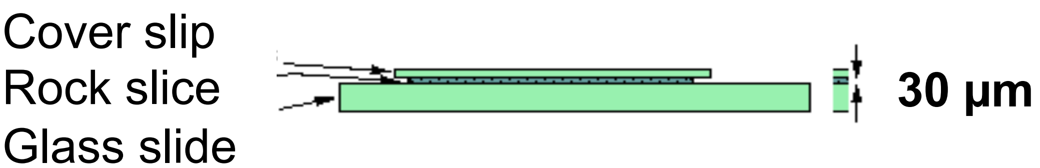
- Maximum resolution, d:

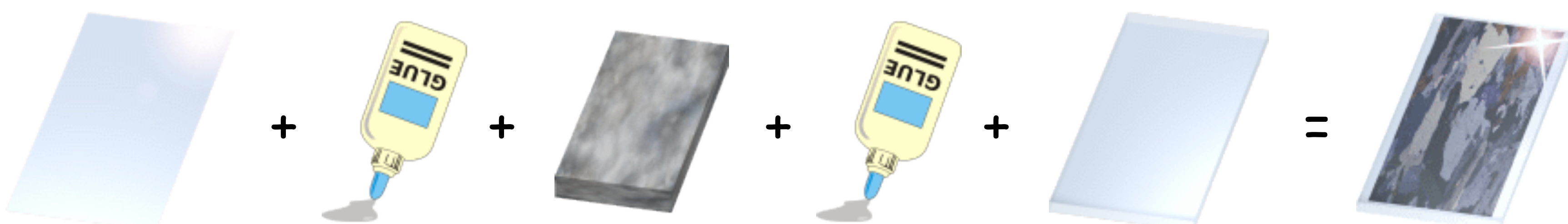
$$d = \frac{\lambda}{2A}$$

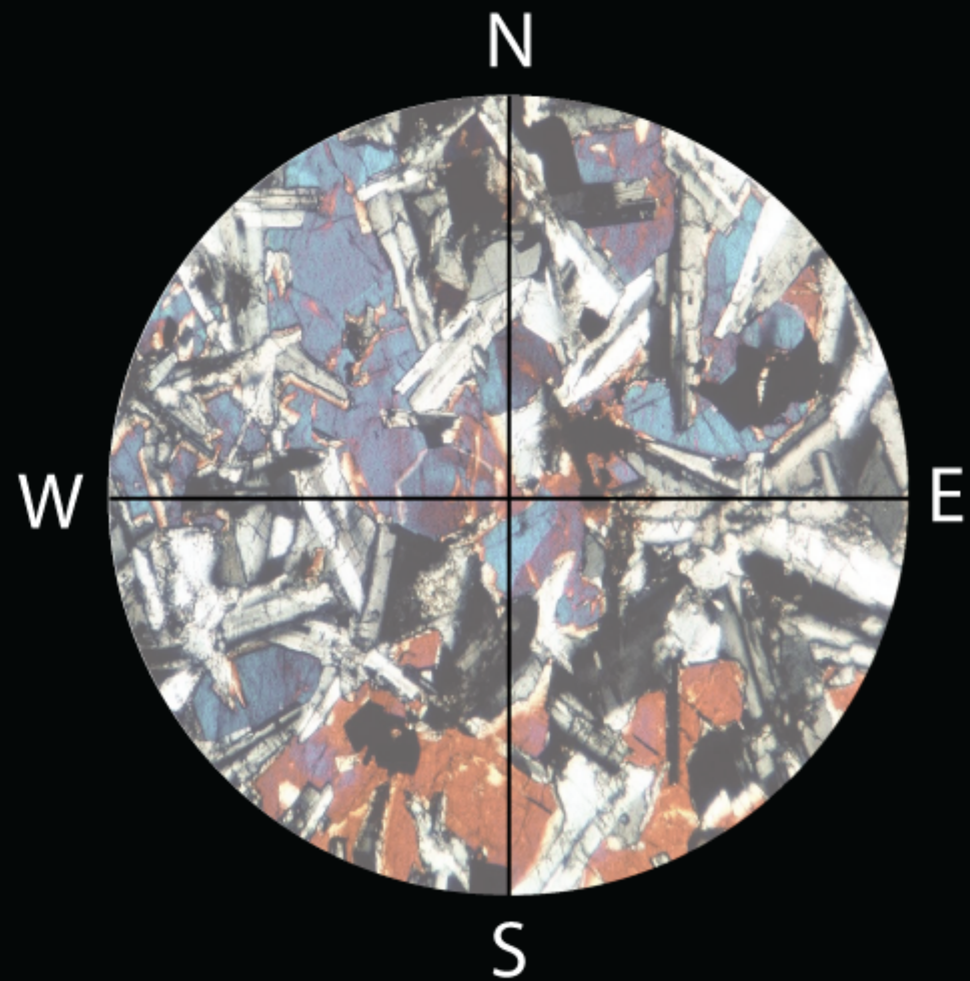


Thin Sections

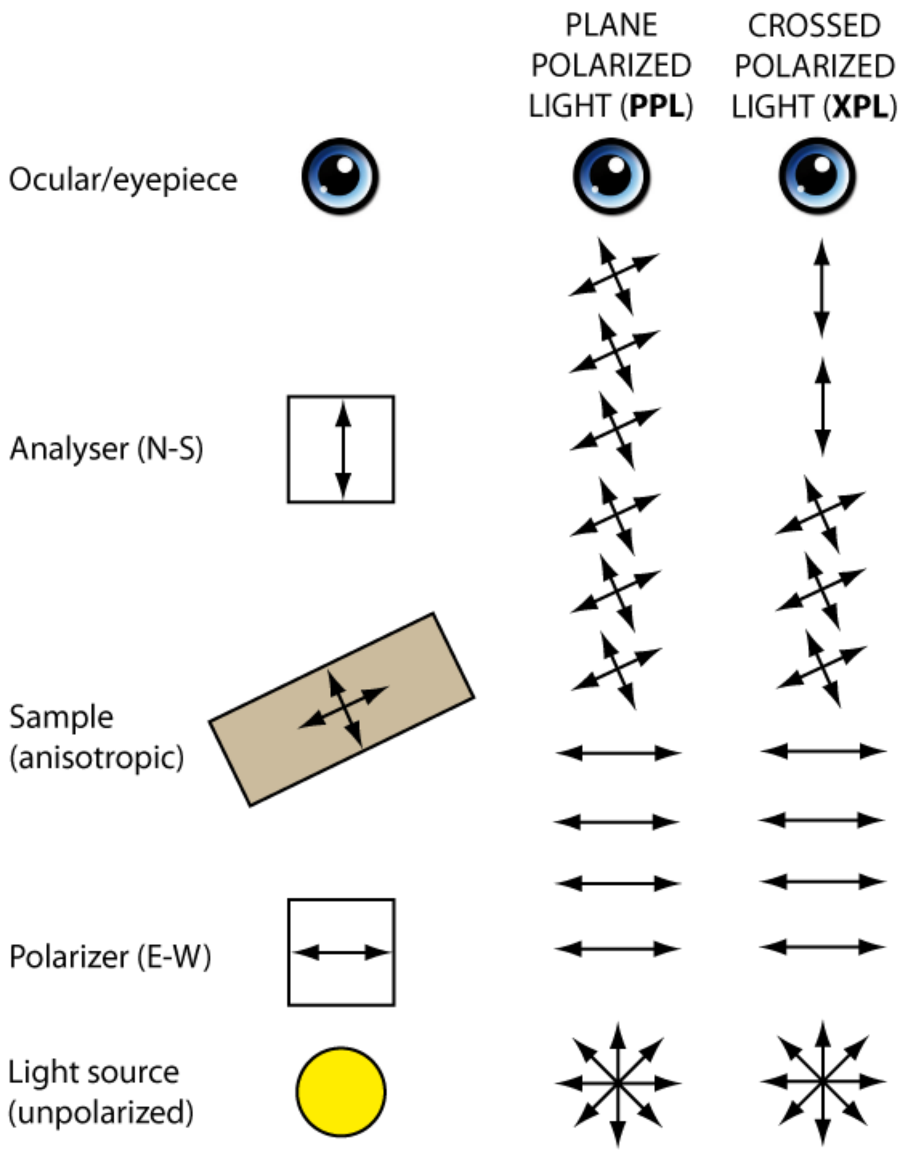
- Glass slide
- Glue (Epoxy resin)
- Thin rock slice (**30 µm = 0,03 mm**)
- Glue (***n* = 1,54**)
- Glass cover slip






N
W
E
S

The Polarizing Microscope



Orthoscopic Microscopy

Orthoscopic (parallel light) observations can be made in:

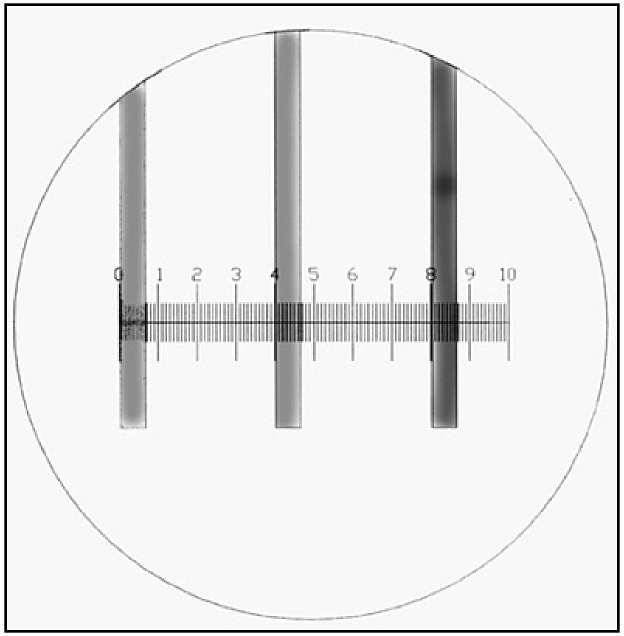
- PLANE POLARISED LIGHT (PPL) - with the analyser **OUT**
  - crystal shape/habit
  - colour/pleochroism
  - cleavage/fracture
  - relief, Becke test → refractive index estimation

- CROSSED POLARISED LIGHT (XPL) - with the analyser **IN**
  - birefringence
  - extinction angle
  - twinning and zoning

PPL - Grain size

- Using a ruler, measure the field of view for each objective lens

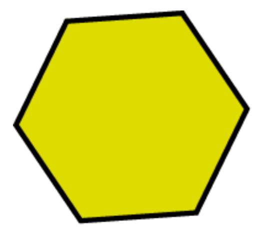
- This can then be used to measure maximum and minimum grain-size and grain-size ranges….



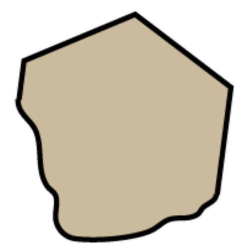
PPL - Crystal habit (shape)

- Thin sections are 2d cuts through 3d crystals
- Habits dependent on crystal system, the angle of cut and how perfectly formed the crystals are:

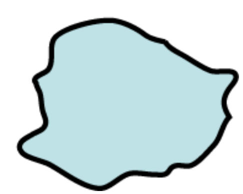
★ EUHEDRAL
= idiomorphic



★ SUBHEDRAL
= hypidiomorphic



★ ANHEDRAL
= xenomorphic



PPL - Crystal habit (shape)

★ EUHEDRAL
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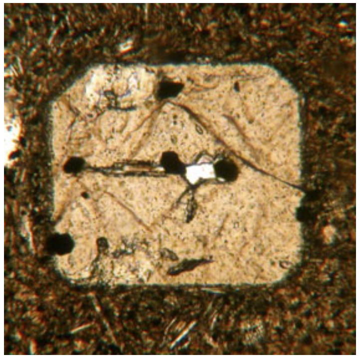

★ SUBHEDRAL
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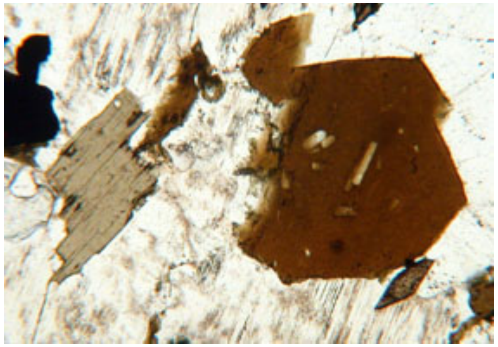

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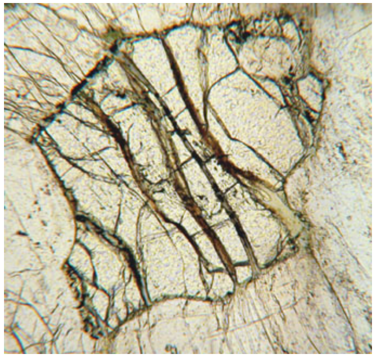
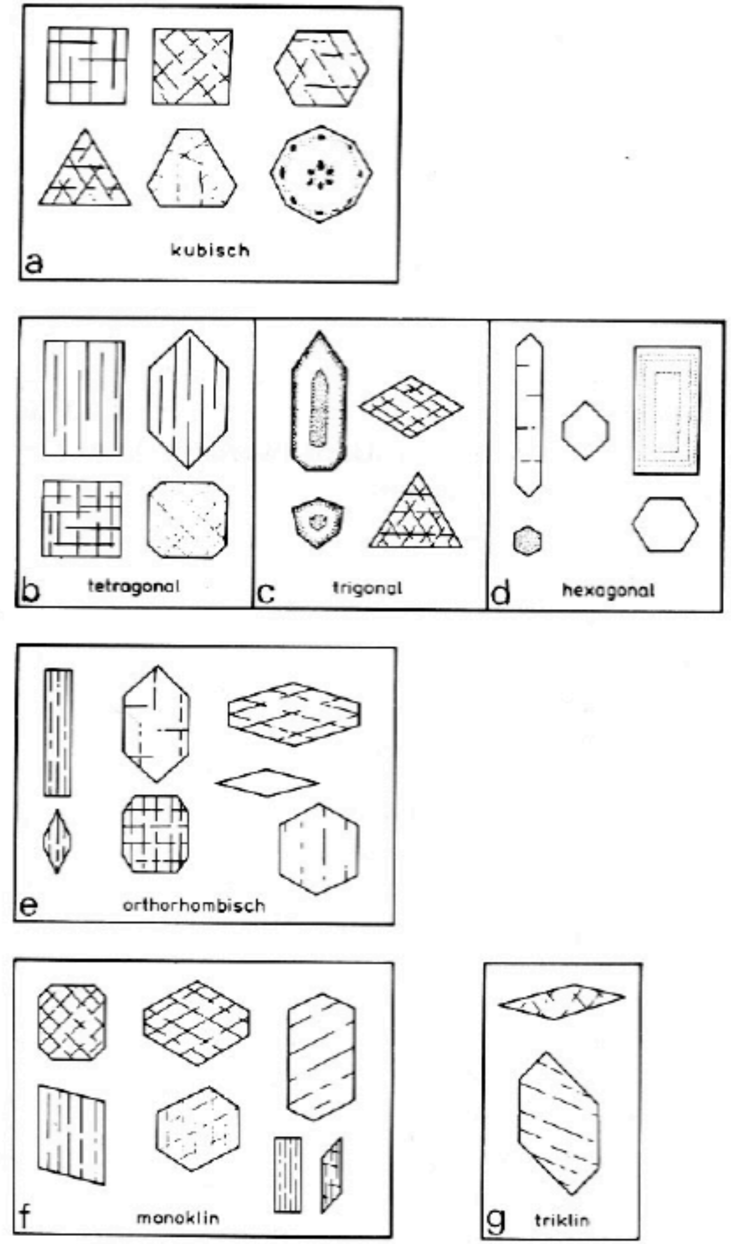


Crystal habits

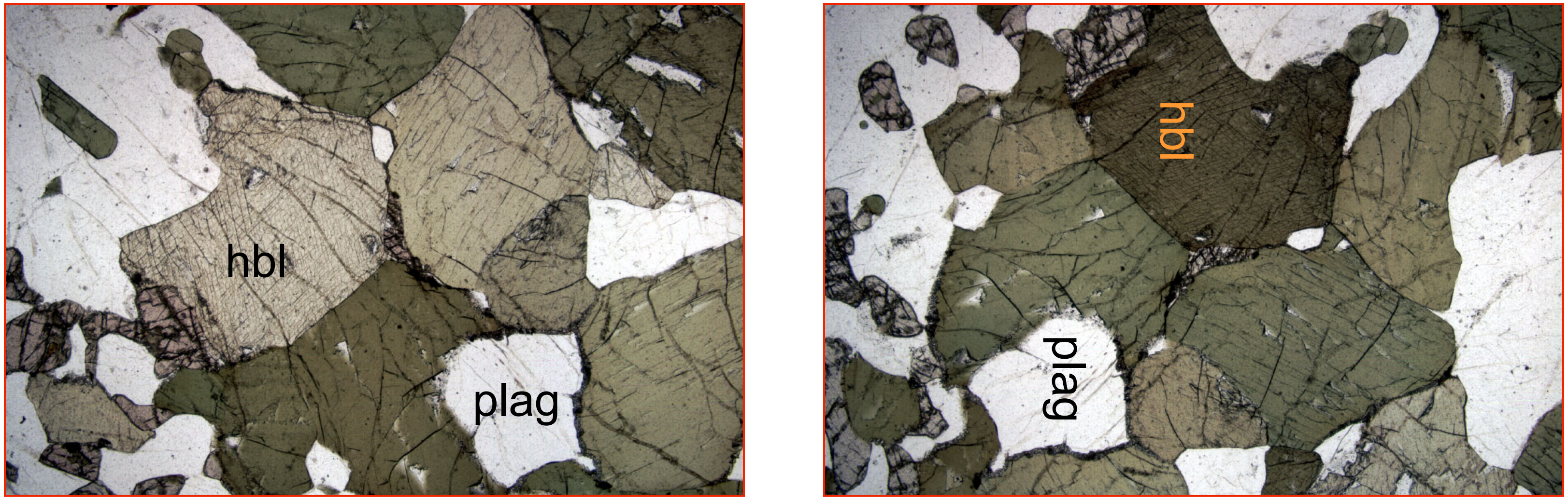
Acicular	Needle-like
Bladed	Blade-like
Equant	Length & width roughly equal
Fibrous	Slender prisms
Poikiloblastic	With many inclusions
Prismatic	Elongate, prism-like
Tabular	Tablet-shaped

….etc., etc.….



PPL - Colour & Pleochroism

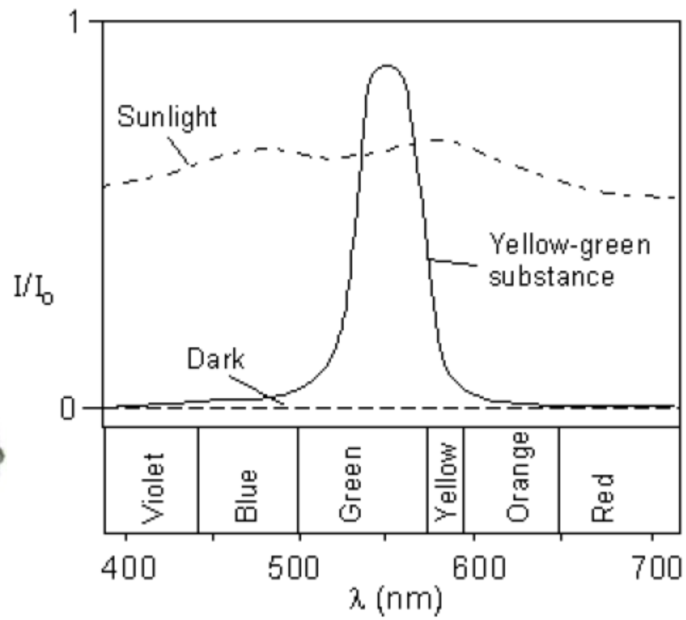
- Colour is caused by selective absorption of certain wavelengths
- Colour (absorption colour) must **always** be observed using PPL
- Pleochroism = direction controlled absorption
  - different colours depend on crystallographic orientation measured by rotating the microscope stage

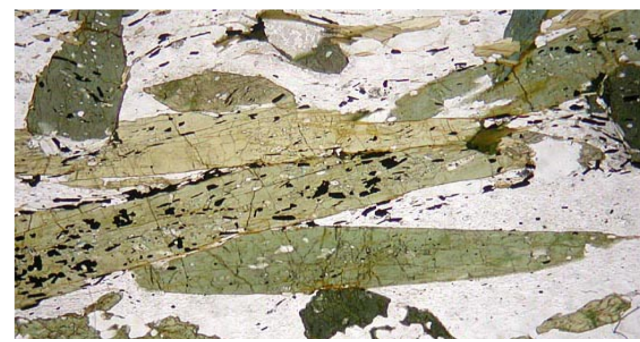


- Plagioclase is colourless
- Hornblende is pleochroic: light green to olive green

Absorption and Colour

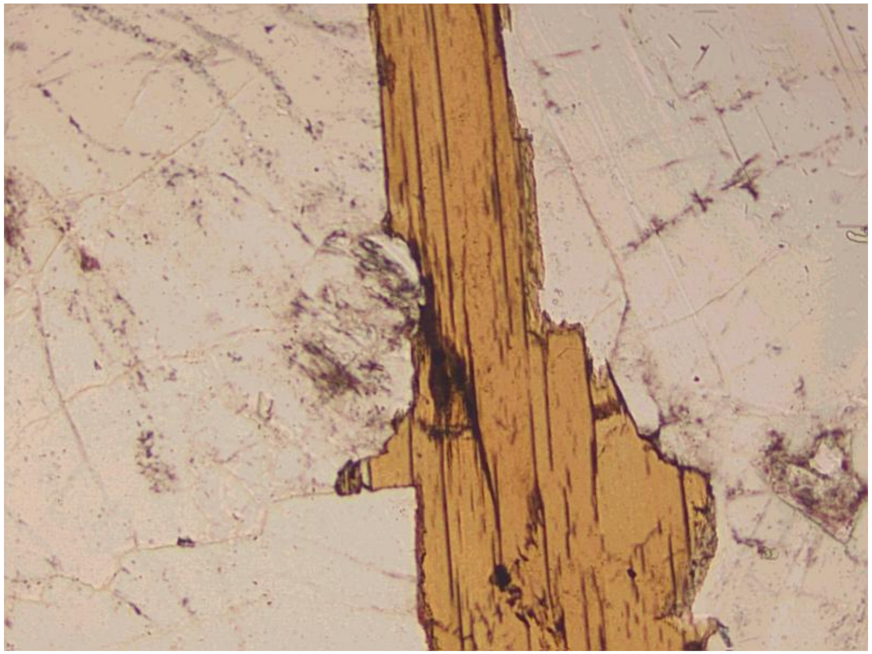
- Selective absorption of certain wavelengths → Absorption colour
- The absorption colour is complimentary to the absorbed wavelengths!
- An example: a green mineral (e.g. hornblende):
  - Red/orange and blue/violet wavelengths are absorbed
  - Transparent for green light



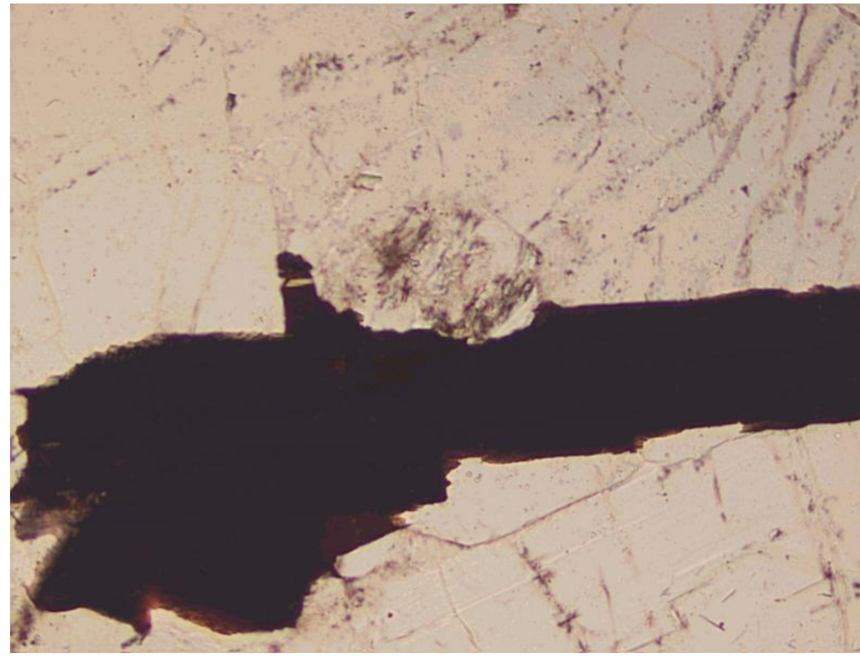


Note: Very rarely, colour effects are from interference and diffraction

Pleochroic scheme: Biotite



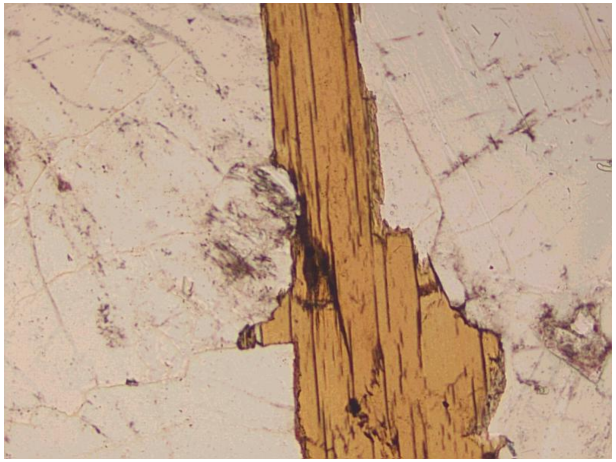
Pale brown N-S

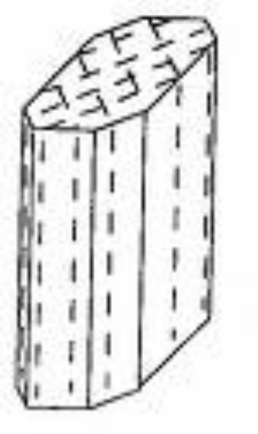


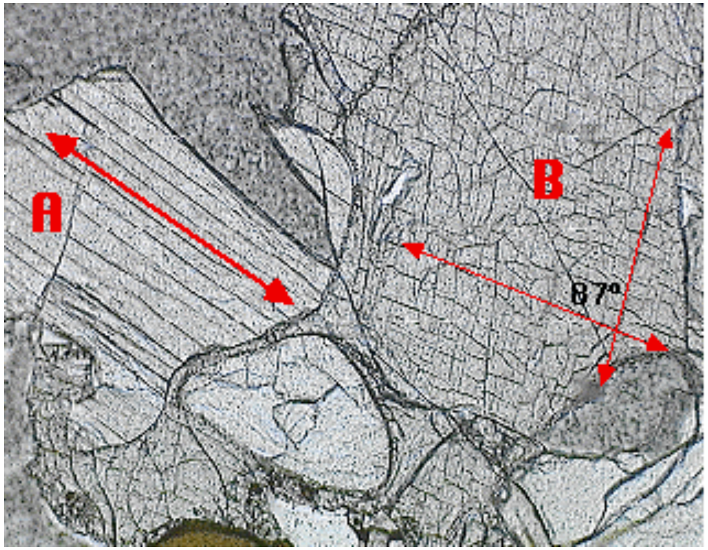
Dark brown E-W

PPL - Cleavage

- How many?
  - e.g., 0, 1, 2
- Angular relationship?
  - e.g., 90°, 60°
- How well developed?
  - Weak, moderate, good





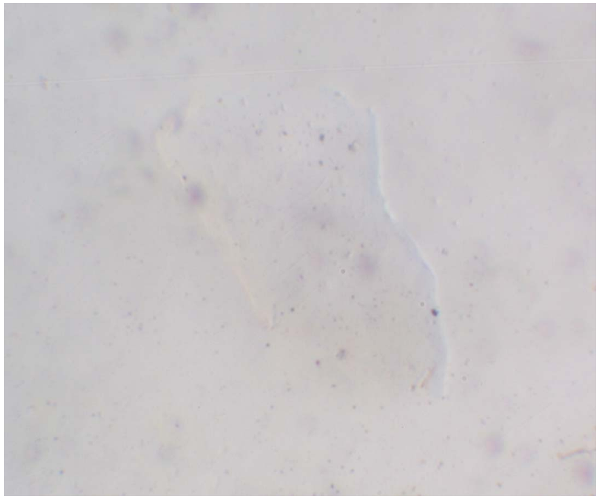


- Beware - Fractures can be easy to mistake as cleavage!

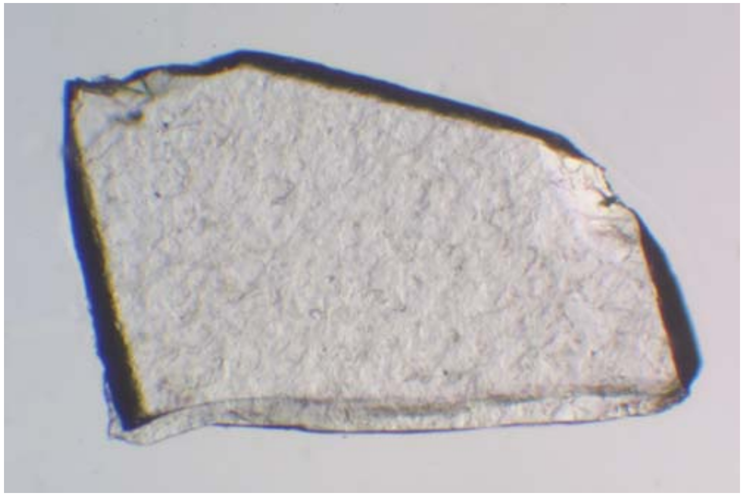
PPL - Relief

- The amount that a mineral *stands out* in the section
- Can be absent, low, moderate, high or very high
- Relief is a measure of the **relative** refractive index (Δn) between the mineral and the epoxy (glue)
- Relief can provide an estimate **of** ***n***

Garnet:	n = 1,72-1,89
Quartz:	n = 1,54-1,55
Epoxy:	n = 1,54



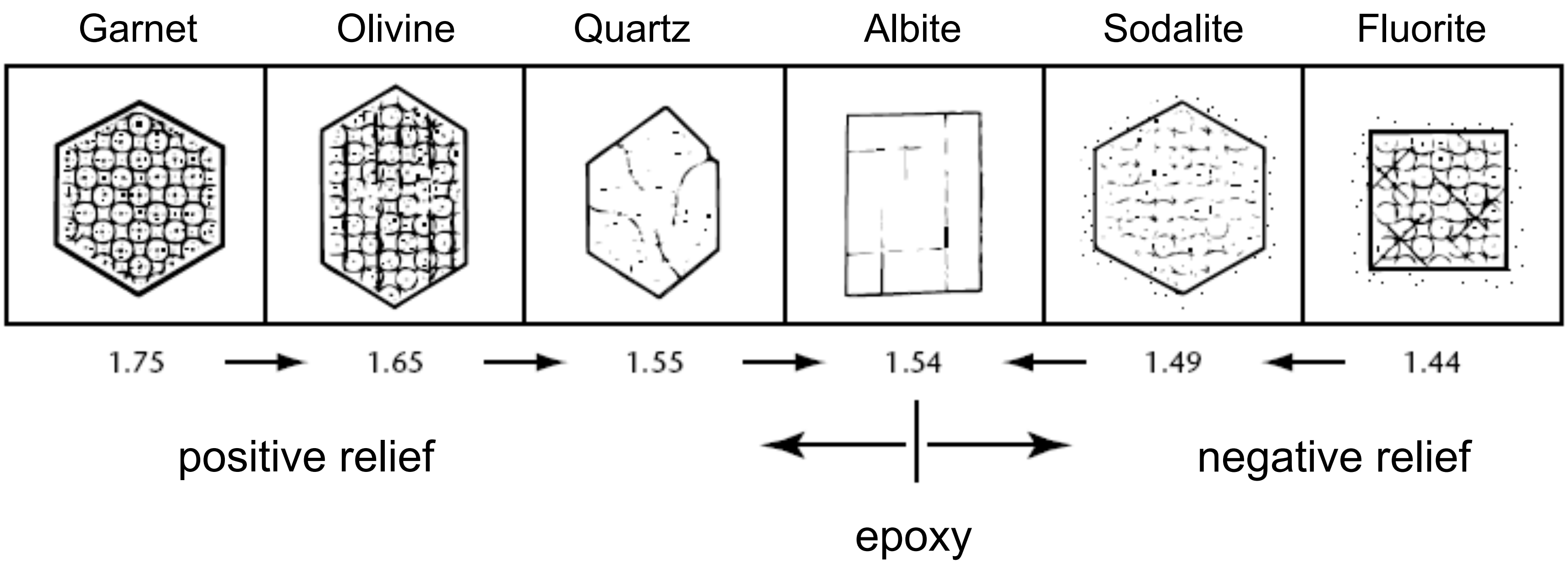
Quartz: very low relief



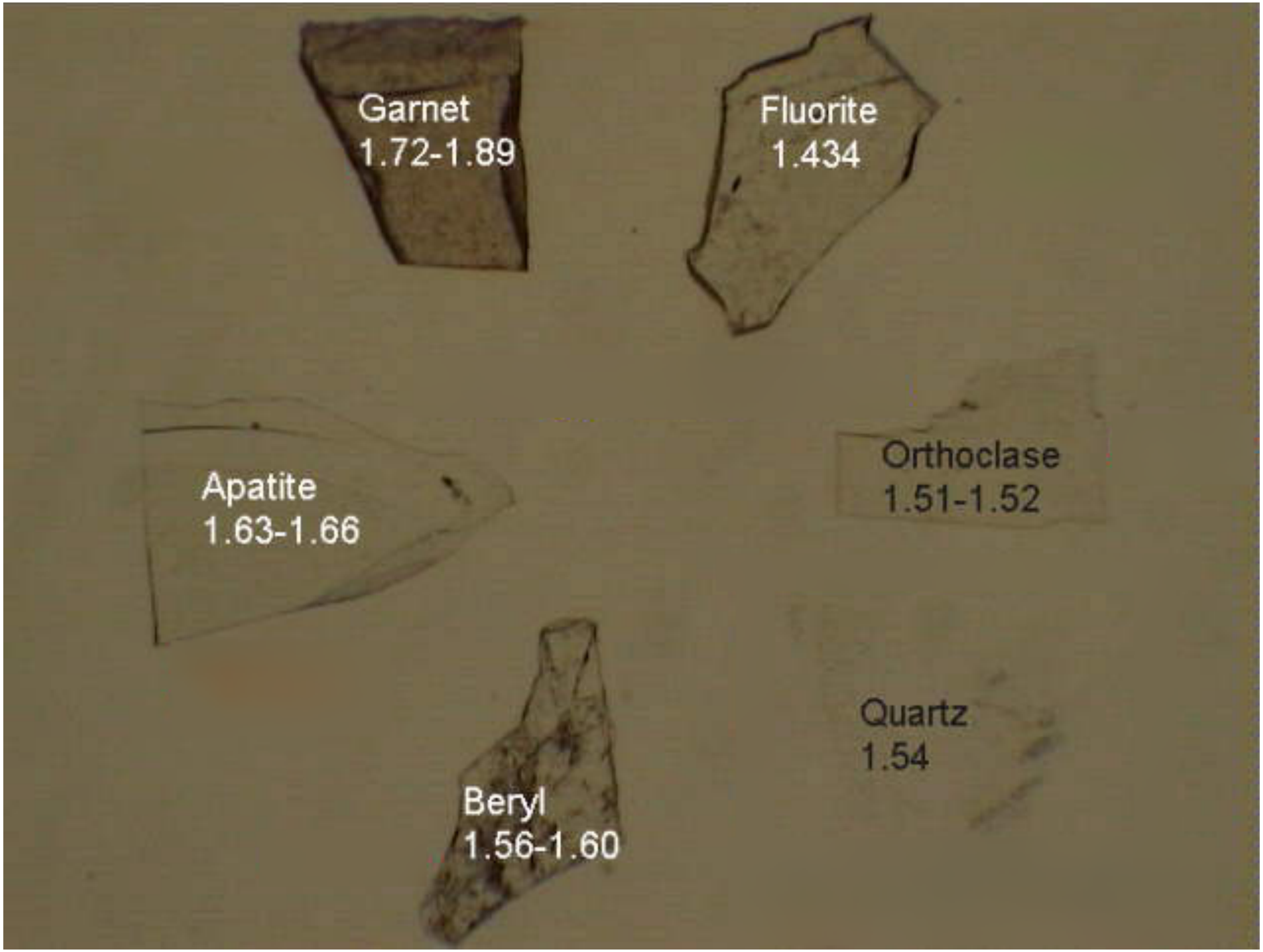
Garnet: high relief

Relief

Relief can be positive or negative. A mineral can have moderate relief but a refractive index lower than the epoxy (e.g. fluorite):



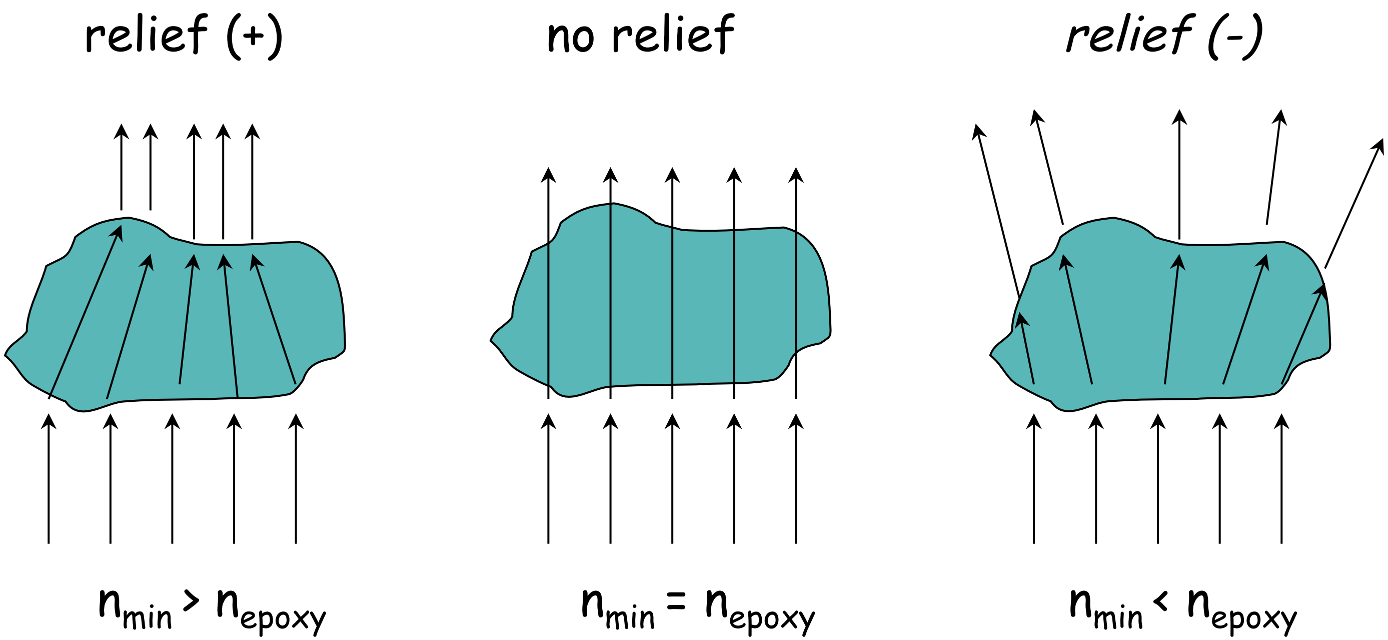
Relief



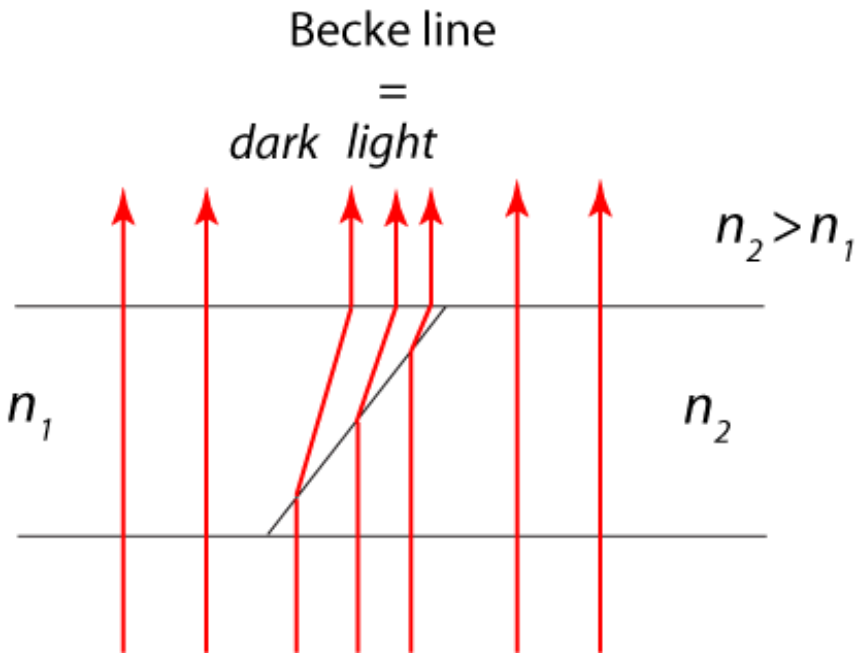
Garnet
1.72-1.89
Fluorite
1.434
Apatite
1.63-1.66
Orthoclase
1.51-1.52
Quartz
1.54
Beryl
1.56-1.60

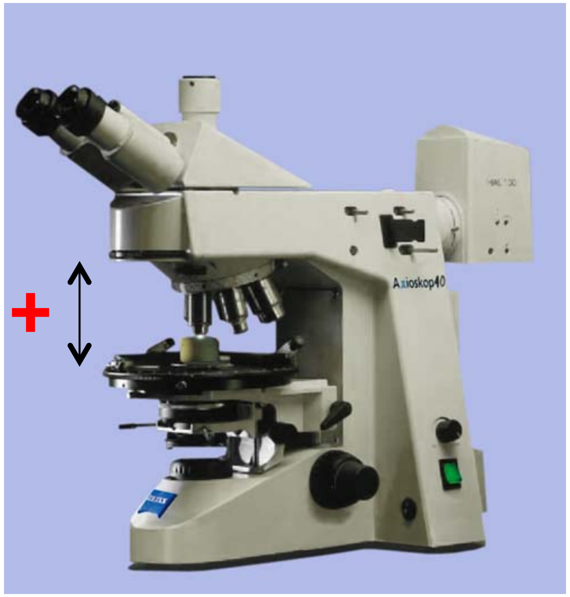
Why do we see relief?

Minerals with different refractive indices (*n*), cause diffraction, refraction and reflection of the light at grain boundaries:



Becke Line

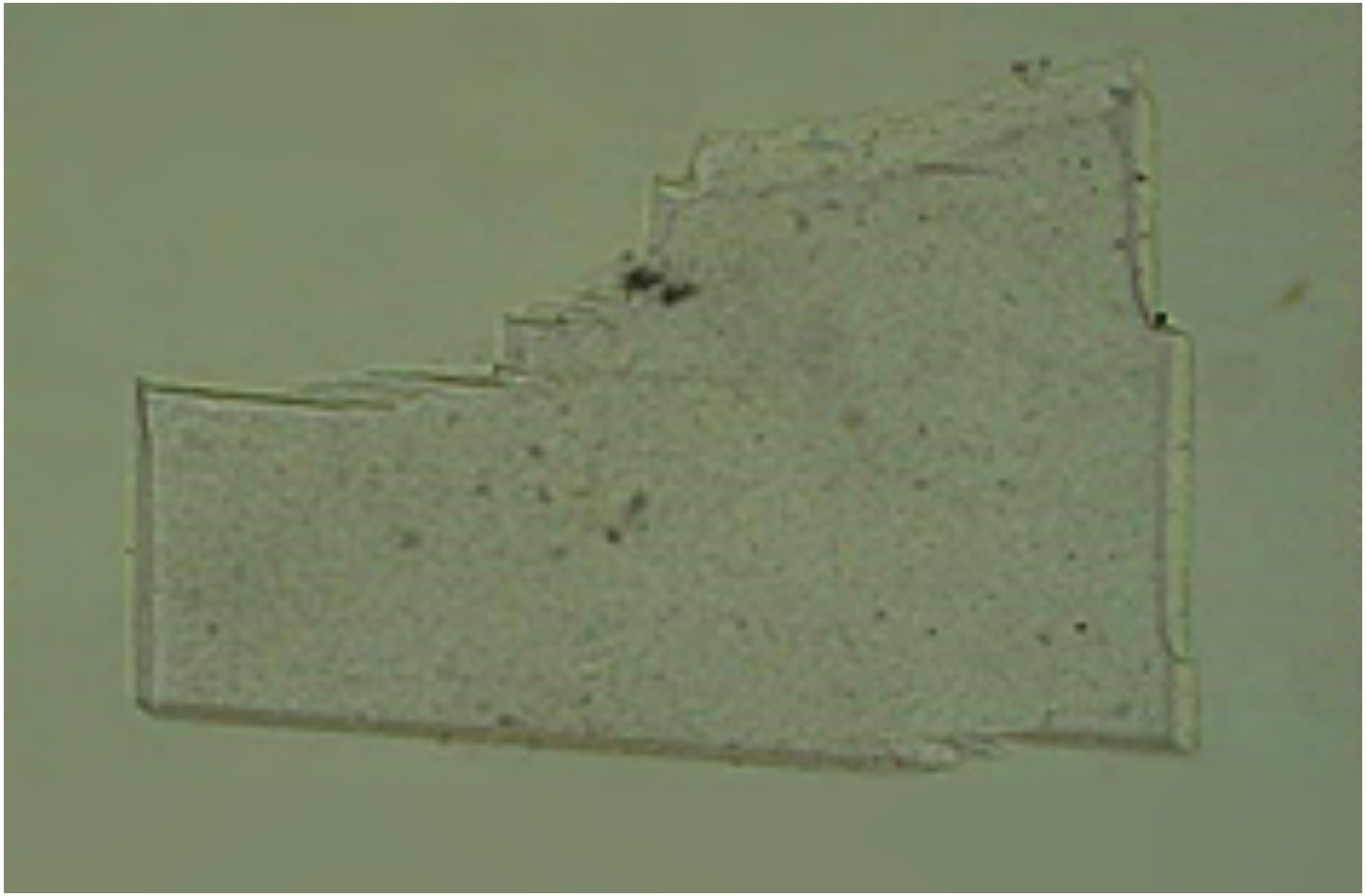




- As you lower the stage (i.e. increase the distance between the objective and sample), the Becke line moves into the mineral of higher relief….OR….

- HHH = Beim Herablassen des Tisches wandert die helle Linie in das höherbrechende Mineral.

Becke Line



The Polarizing Microscope